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## Soft Layer Modelling

*at Aarhus University and Aalborg University*

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# Project Litaseis

fifth periodic report

Soft layer modelling

at

Aarhus University and Aalborg University

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## RESONANT COLUMN TESTS

During the winter 1994/95 resonant column tests have been carried out on some samples from the actual site at Nr. Lyngby.

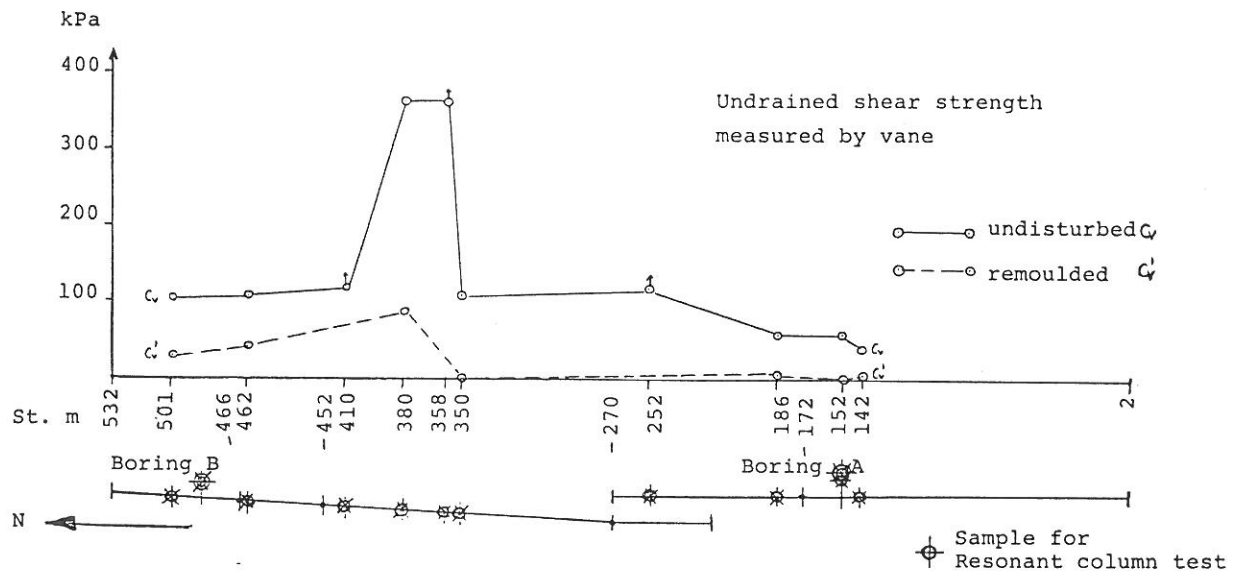


Fig. 1. Position of the tested samples in relation to the shallow reflection seismic profiles, and the undrained shear strength measured by vane in 2,2 meters depth.

### Samples tested

3 samples extracted from the clayey sediments in 2 meters depth

in station 462,	$l = 121$ mm,	$d = 71,8$ mm,	$\gamma = 20,0$ kN/m <sup>3</sup> ,	$w = 29$ %,
in station 380,	$l = 137$ mm,	$d = 71,8$ mm,	$\gamma = 21,6$ kN/m <sup>3</sup> ,	$w = 23$ %,
in station 186,	$l = 134$ mm,	$d = 71,8$ mm,	$\gamma = 19,4$ kN/m <sup>3</sup> ,	$w = 24$ %,

2 samples extracted from the clayey sediments in 4,5 meters depth

in boring B,	$l = 146$ mm,	$d = 71,8$ mm,	$\gamma = 20,5$ kN/m <sup>3</sup> ,	$w = 23$ %,
in boring A,	$l = 125$ mm,	$d = 71,8$ mm,	$\gamma = 19,0$ kN/m <sup>3</sup> ,	$w = 30$ %,

1 sample extracted from the clayey sediment in 16 meters depth

in boring B,	$l = 92$ mm,	$d = 71,8$ mm,	$\gamma = 22,7$ kN/m <sup>3</sup> ,	$w = 20$ %,
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### Test procedure

Piezoceramic bender elements were installed in both ends of the samples, and the samples were placed on a shaking table.

The samples were encapsulated in latex membranes and by vacuum subjected to an all round pressure as close as possible to the preconsolidation pressure as determined by oedometer tests.

After consolidation at the preconsolidation pressure, the samples were consolidated at an all round pressure close to the in situ pressure.

### Determination of the shear modulus, $G$ .

After consolidation at the in situ pressure, the initial shear modulus is determined by the bender element method.

A shear wave is propagated from the transmitter element at the top of the sample and received at the receiver element at the bottom of the sample. The travel time of the shear wave is determined on an oscilloscope as the time difference between the rise of the square wave driving signal and the first significant jump in the receiver signal. The shear wave velocity,  $v_s$ , for the soil sample can then be determined as well as the initial shear modulus,  $G_{max}$ .

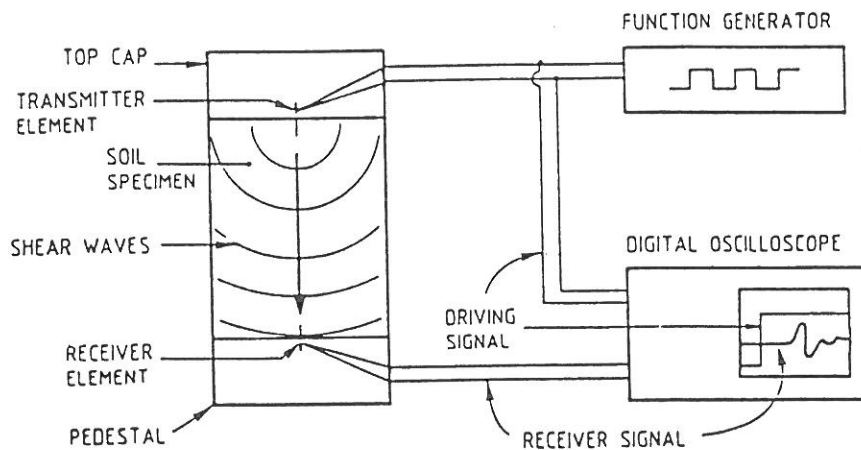


Fig. 2. Setup for the incorporating bender elements in the resonant column apparatus.

(Rune Dyvik and Christian Madhus, *Lab Measurements of  $G_{max}$  Using Bender Elements*)

### Determination of Young's modulus, $E$ , and the damping of the material, $D$ .

After determination of the shear modulus, tests are carried out on the same sample to determine Young's modulus.

Oscillations from the shaking table are transferred to the sample, and displacements at the bottom and the top of the sample are determined by accelerometers placed at the base cap and the top cap. By variation of the frequency the variation of the amplification factor ( $H$ ) with the frequency are determined.

When the frequency is equal to the natural frequency of the sample the amplification factor shows a sharp rise, and a resonant point is found. On the basis of the frequency at the resonant point the wave velocity and then the Young's modulus,  $E$ , are determined.

The damping of the material is estimated from the size of the amplification factor.

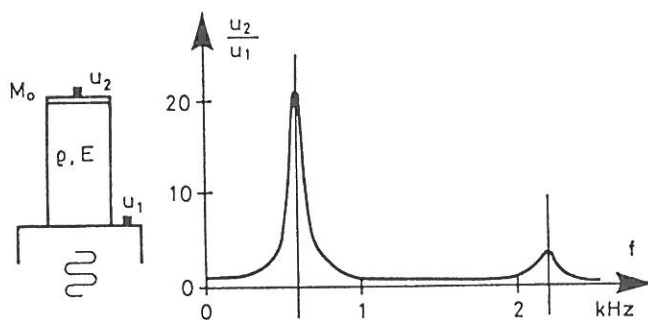


Fig. 3. Resonant column test. Longitudinal oscillations.

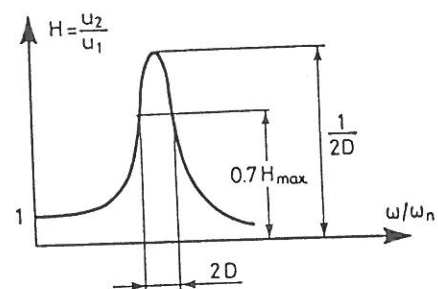


Fig. 4. Estimation of the damping,  $D$

### Control

After the test to determine Young's modulus, a new test for determination of the initial shear modulus was carried out as a control for changes in the soil material.

### Additional tests

After the tests at the in situ pressure, the sample was subjected to other pressures, and the same test procedure carried out, resulting in a variation with stress of Young's modulus,  $E$ , and the initial shear modulus,  $G_{\max}$ , respectively.

## Results

### Determination of the initial shear modulus

The results of the determination of the initial shear modulus,  $G_{\max}$ , are shown in fig. 5 and fig. 5.

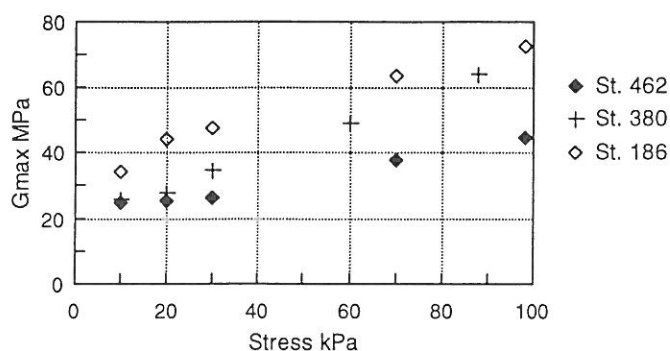


Fig. 5.  $G_{\max}$  determined for samples from 2 meters depth in station 462, 380 and 186.

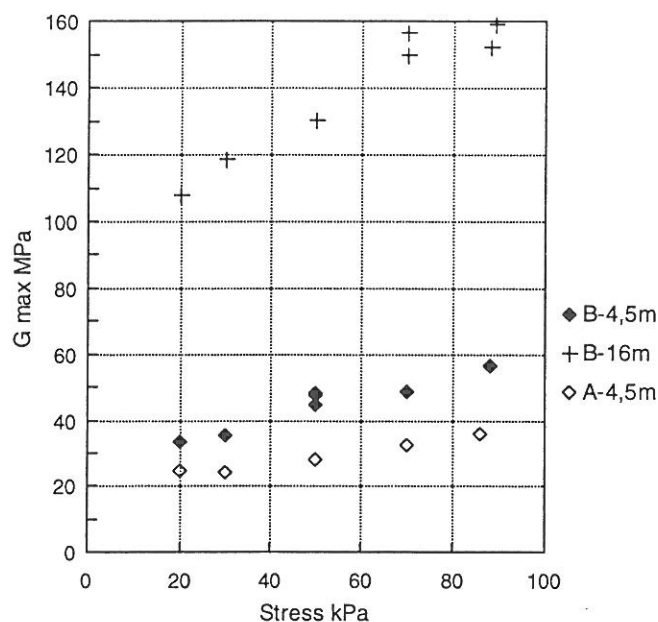


Fig. 6.  $G_{\max}$  determined for a sample from 4,5 meters depth from boring A, and a sample from 4,5 meters depth and 16 meters depth from boring B.

### Determination of Young's modulus

The results of the determinations of Young's modulus from the resonant column tests,  $E_{\text{test}}$ , are shown in fig. 7 and fig. 8.

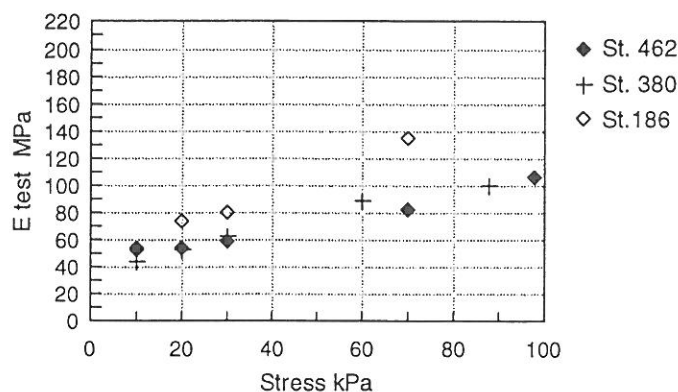


Fig. 7.  $E$  determined by resonant column tests for samples from 2 meter's depth in station 462, 380 and 186.

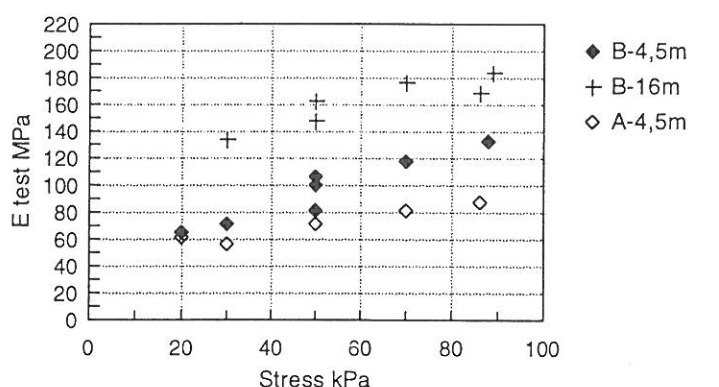


Fig. 8.  $E$  determined from resonant column tests for a sample from 4,5 meter's depth in boring A, and from 4,5 and 16 meter's depth in boring B.

Young's modulus varies with the strain, and the strain has not been constant during the resonant column tests.

For the sample from 16 m in boring B the strain has been measured to about  $1 \cdot 10^{-6}$ , for the other samples, the strain has varied from  $2 \cdot 10^{-6}$  to about  $40 \cdot 10^{-6}$ .

The above values of  $E$  are therefore possibly not to be correlated directly.

For very small strains the Poisson ratio is assumed to be very close to  $\mu = 0,5$ .

In the bender element tests the strains are very small, and a value for  $E$  at very small strains therefore could be calculated from the determined value of  $G$  and  $\mu = 0,5$ .

The calculated values for  $E$  are shown below in fig. 9 and fig. 10.

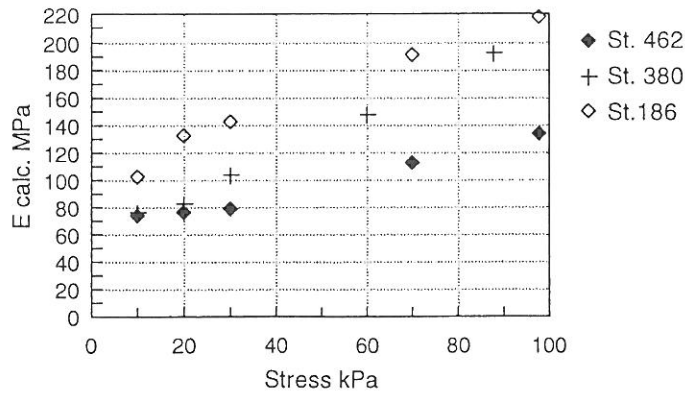


Fig. 9.  $E$  calculated from  $G$  and  $\mu = 0,5$ , for samples from 2 meters depth in station 462, 380 and 186.

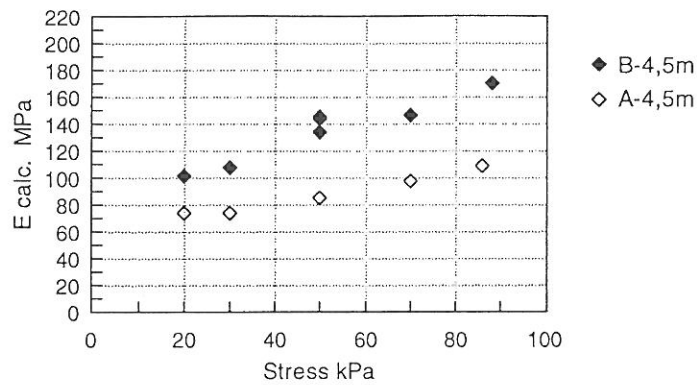


Fig. 10.  $E$  calculated from  $G$  and  $\mu = 0,5$  for the samples from 4,5 meters depth in boring A and boring B.

#### *Damping of the material*

The damping of the material,  $D$ , is estimated from the size of the amplification factor,  $H$ ,  $D = 1/(2H)$ . The results are shown below in fig. 11. and fig. 12.

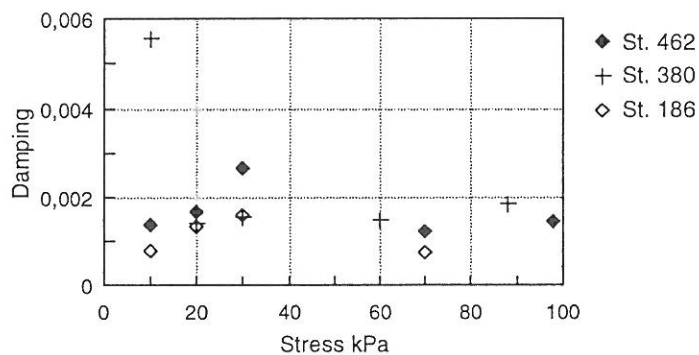


Fig. 11. Damping,  $D$ , for the samples from 2 meters depth in station 462, 380 and 186.

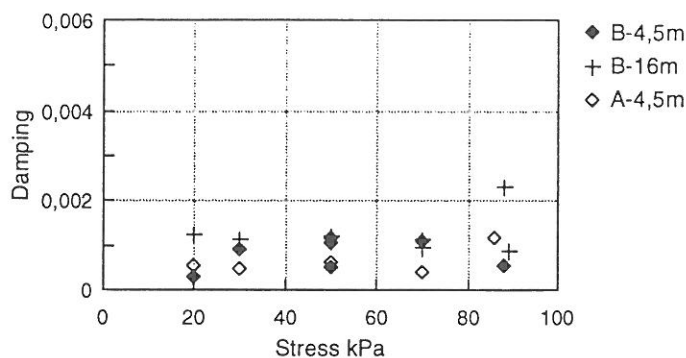


Fig. 12. Damping,  $D$ , for a sample from 4,5 meters depth in boring A, and from 4,5 and 16 meters depth in boring B.

### Conclusion

The results of the resonant column tests so far have not shown any great difference in the measured parameters of the samples from shallow depth in the area around boring B and the area around boring A.

### Supplementary tests

Supplementary tests have been carried out in order to improve the understanding of the results from the resonant column tests.

After the test with a sample from st. 186,  $l = 134$  mm, a test with the bender elements was carried out with the sample shortened to  $l = 30$  mm, in order to observe the influence of the length of the sample.

The results of the tests carried out at small round pressures of 10, 20 and 30 kPa are shown in fig. 13.

The results indicate very little influence of the length of the sample.

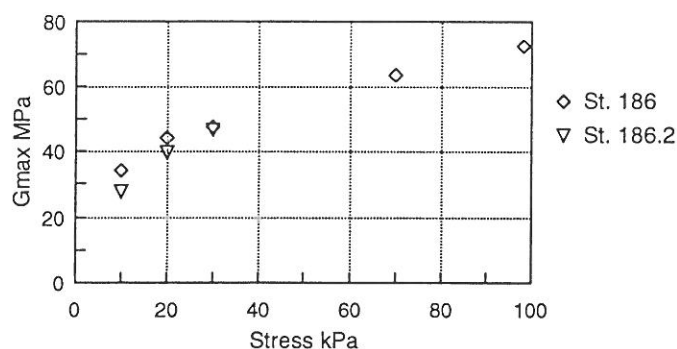


Fig. 13. Comparison of  $G_{max}$ , determined with a sample 186.2,  $l = 30$  mm, and 186,  $l = 134$  mm.

At the Norwegian Geotechnical Institute tests are carried out with a sample from 4,4 meters depth from boring A. The size of the tested sample was  $l = 109,4$  mm,  $d = 55,62$  mm. Tests have been carried out in an apparatus, in which torsional motions could be applied as well as with the bender elements.

The purpose of the tests was to get information about the variation in  $G$  with the strain, and to investigate the difference in  $G$ , determined in a torsion apparatus and by the bender elements. The analyses of the tests are not finished, but the results seem to indicate, that for strains below  $10^{-4}$  the variation in the value of the shear modulus,  $G$ , is minimal, and equal to the value determined by the bender element method.